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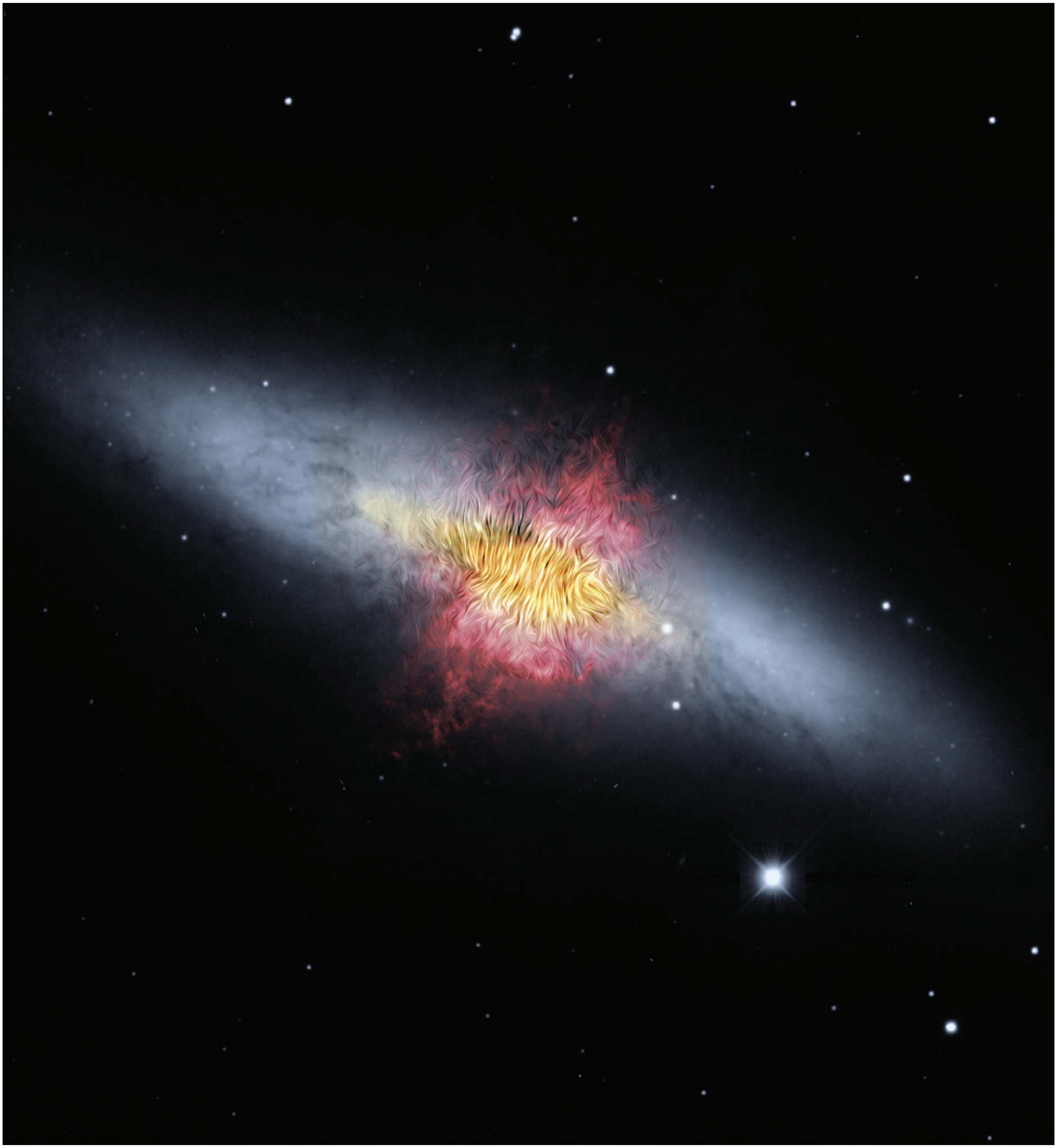

Composite image of the Cigar Galaxy (also called M82), a starburst galaxy about 12 million light-years away in the constellation Ursa Major. See Science Spotlight, page 7. *(NASA/SOFIA/E. Lopez-Rodiguez; NASA/Spitzer/J. Moustakas et al.)*

Director's Message

Harold Yorke, *Science Mission Operations Director*

The last six months have seen the completion of two high-level, comprehensive, complementary, reviews of the SOFIA program. The SOFIA Operations and Mission Efficiency (SOMER) review evaluated aircraft operations, while the Five-Year Flagship Mission Review (FMR) focused on the science priorities and operations. Both reviews were initiated and organized by NASA, and the panels comprised high-level reviewers from peer organizations. Both reviews included significant participation (inputs and reviewers) from our German partners. As is usual with this type of review, the program summarized scientific accomplishments and developed a proposal for the future operations of SOFIA including a long-range vision for the observatory. While the FMR proposal is not public, the science vision has been summarized in two white papers (on star formation and galaxy evolution) for the 2020 Decadal Survey. The SOFIA program hosted the SOMER review panel in late January (at NASA Armstrong/Palmdale) and the FMR panel in April (at NASA Ames).

The long government shutdown in December–January caused a significant loss of flight opportunities for SOFIA, including forcing the cancellation of the planned visit to the January AAS meeting in Seattle, Washington. In addition, the planned Faint Object infraRed CAmera for the SOFIA Telescope (FORCAST) and Echelon-Cross- Echelle Spectrograph (EXES) winter/spring series were fully lost. Thanks to the flexibility and hard work of the SOFIA planning and science staff, short series for both the High-Resolution Airborne Wideband Camera-plus (HAWC+) and Far Infrared Field-Imaging Line Spectrometer (FIFI-LS) were rescheduled after the shutdown ended and before the long-planned spring aircraft maintenance period. Despite these losses only a small number of Priority 1 programs were lost. These have been integrated into the Cycle 7 planning and will be executed during the coming year. The first "Thesis Enabling Program" (advisor Wiklind, student Motino, from Catholic University of America) was completed in the rescheduled spring HAWC+ and FIFI-LS series. The annual observing plan for Cycle 7 is complete, including selecting the first two "SOFIA Legacy Programs." ■

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SOFIA SENIOR SCIENCE LEADERSHIP

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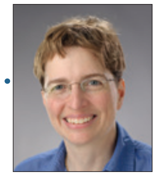

The Universe's First Type of Molecule is Found at Last

Researchers using SOFIA have made the first-ever detection of the helium hydride molecular ion (HeH^+) in interstellar space. This discovery refines our understanding of the underlying chemical networks that control the formation and destruction of this special molecular ion, a first step toward the huge diversity of molecules in the Universe today.

Understanding how that early gas (mostly hydrogen and helium) evolves into the Universe filled with galaxies, stars, and planets we see today, some 13.8 billion years later, remains one of the most important goals of modern astrophysics. When temperatures in the early Universe had fallen below ~4,000 K, the light elements produced in the Big Bang began to combine. Ionized hydrogen interacting with neutral helium created the "Universe's first molecular bond" in the helium hydride ion (HeH^+). Destruction of HeH^+ created one of the earliest paths to forming molecular hydrogen (H_2), the most abundant and significant molecule in the Universe. The growing abundance of such molecules influenced the structure of the early Universe by providing a dominant mechanism for gas to cool and form stars.

Having been predicted by chemical models and created in the laboratory, decades-long searches for this elusive molecule in an astrophysical environment turned up short — until now.

HeH^+ was detected toward the planetary nebula NGC 7027 with the German REceiver for Astronomy at Terahertz Frequencies (GREAT) spectrometer aboard SOFIA. The hard radiation field produced by the central white dwarf star (T > 100,000 K) combined with a high density of hydrogen and helium, proved to be an excellent place where HeH^+ could form today. Comparing the observed *J=1-0* emission at 149 microns to detailed models of the nebula's helium and hydrogen ionization fronts, the team found the observed flux was a factor four times brighter than predictions. The results constrain the radiative association creation ($He^+ + H \rightarrow HeH^+ + h\nu$) and the dissociative recombination rates ($HeH^+ + e^- \rightarrow He + H$) in the NGC 7027 environment. This in turn may stimulate future advance studies of these important reactions and of the corresponding radiative association under conditions

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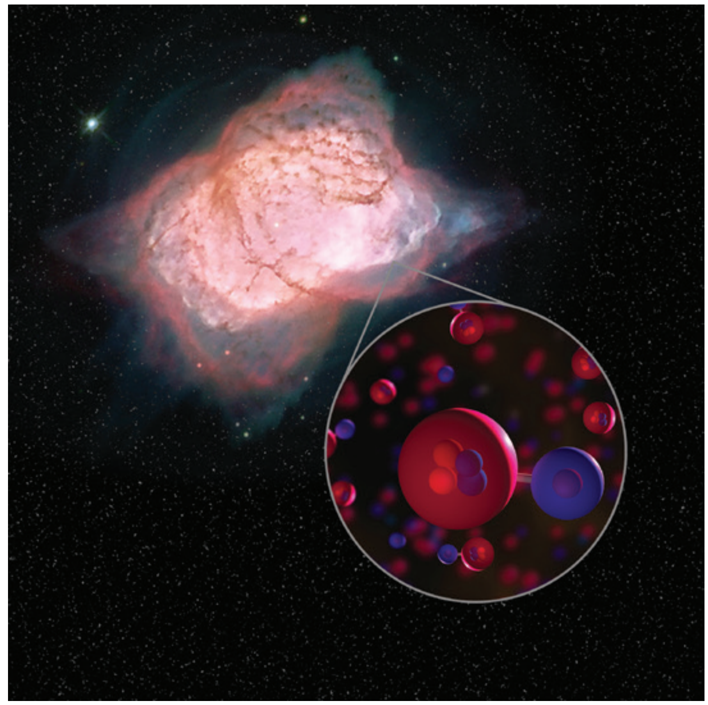


Image of planetary nebula NGC 7027 with illustration of helium hydride molecules. In this planetary nebula, SOFIA detected helium hydride, a combination of helium (red) and hydrogen (blue), which was the first type of molecule to ever form in the early universe. This is the first time helium hydride has been found in the modern universe. *(NASA/ESA/Hubble Processing: Judy Schmidt)*

About this Spotlight

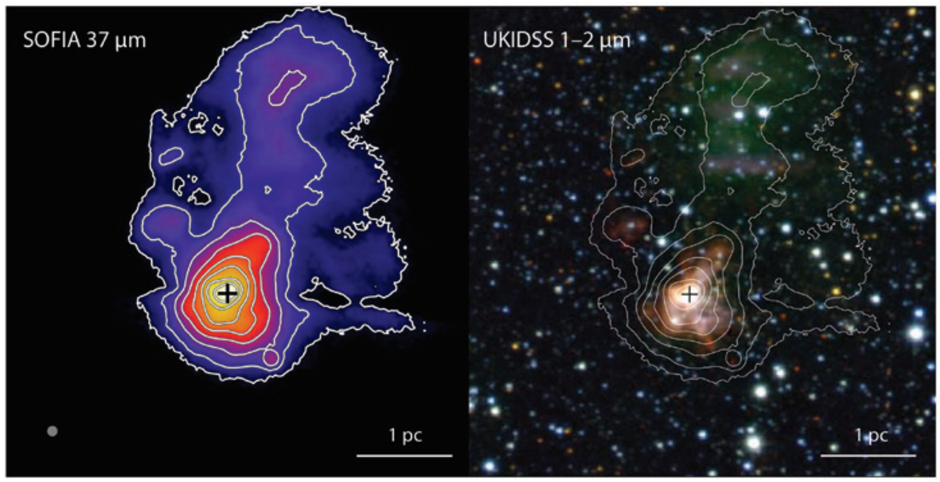
Paper: Astrophysical detection of the helium hydride ion HeH^+
Authors: R. Güsten, H. Wiesemeyer, D. Neufeld, K. Menten, U. U. Graf, K. Jacobs, B. Klein, O. Ricken, C. Risacher, J. Stutzki
Reference: 2019, Nature, 568, 357.

Science Spotlight

Mengyao Liu, *Ph.D. Student, University of Virginia*
Jonathan Tan, *Research Professor, University of Virginia*
Randolf Klein, *Science Outreach Lead*



The Most Luminous Protostar



Left: SOFIA/FORCAST 37-micron image of the G45.12+0.13 protostar, showing thermal emission from heated dust. The grey circle in lower left shows the beam full-width at half-maximum of 2.9 arcsec. *Right:* A three-color image of the same field of view, using J band (blue), H band (green) and K band (red) data from the United Kingdom Infrared Dark Sky Survey (UKIDSS), revealing a near infrared nebula and surrounding stars of a protocluster. The white contours are the SOFIA/FORCAST data overlaid.

Massive stars burn bright throughout the galaxy and the Universe. During their short, violent lives they impact their surroundings by radiating ultraviolet photons, blowing powerful winds and exploding, terminally, as supernovae, further spreading heavy elements forged in their cores out into the cosmos. By these actions, massive stars, especially those born with more than eight solar masses, help regulate the evolution of galaxies and the birth of other stars and planetary systems.

Massive stars themselves form from the densest, most dust-enshrouded condensations within giant molecular clouds. These regions may, at the same time, fragment into star clusters, and it is debated whether massive stars always form surrounded by a swarm of lower-mass companions. The presence of such a cluster may affect how gas joins the massive star. In particular, traditional theories involving relatively ordered collapse from a gravitationally bound gas core may not apply in such crowded regions. Formation mechanisms involving chaotic, competitive accretion and even agglomerative collisions between protostars have been proposed.

To help uncover the secrets of massive star birth, we are using SOFIA-FORCAST's unique ability to peer deep into molecular clouds at wavelengths about 50-times longer than that of visible light to carry out a survey of many massive star-forming regions that sample different masses, evolutionary stages and environments. The left panel of the figure shows a 37-micron image of G45.12+0.13, about 24,000 light years away and the most luminous source we have discovered to date in this SOFIA Massive (SOMA) star formation survey.

The FORCAST images trace warm dust that is heated by the forming massive star or stars. From these images, plus those from other telescopes, we construct the distribution of flux as a function of wavelength — the spectral energy distribution (SED) — and measure the total luminosity. In the case of G45.12+0.13, this is at least one million times that of our Sun! By comparison with theoretical models, we can estimate that the star has already reached a mass as high as 60-times our Sun's and is continuing to gather more material at a furious rate: another solar mass

(continued on page 14)

About this Spotlight

Paper: The SOFIA Massive (SOMA) Star Formation Survey. II. High Luminosity Protostars
Authors: M. Liu, J. C. Tan, J. M. De Buizer, Y. Zhang, M. T. Beltrán, J. E. Staff, K. E. I. Tanaka, B. Whitney, V. Rosero
Reference: 2019, ApJ, 874, 16.

Science Spotlight




Wanggi Lim, *Postdoctoral Fellow*
James M. De Buizer, *Manager for Science Operations*
Randolf Klein, *Science Outreach Lead*
Joan Schmelz, *Associate Director for Science and Public Outreach*

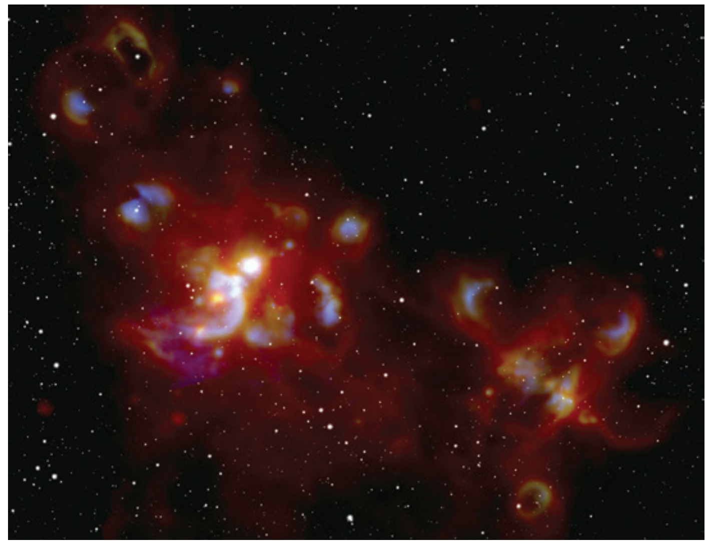
SOFIA Captures Cosmic Light Show of Star Formation

Massive stars play a central role in the shaping of our galaxy, but we are literally in the dark about the details of how they form. SOFIA's infrared vision peered into the heart of W51, the relatively nearby giant star forming region, revealing the cosmic fireworks sparked by massive stars. These mid-infrared observations characterized dozens of young stars, many identified for the first time, and were essential in understanding their early evolutionary states. This study finds that SOFIA's high spatial resolution is a powerful tool to trace deeply embedded massive young stellar objects.

Massive stars like these are rare — less than one percent of all stars. They emit caustic levels of radiation and generate powerful stellar winds that affect the formation of stellar siblings in the natal cloud. Lower mass stars like the Sun have much quieter and humbler origins. So many of these stars are available for study that astronomers understand their birth properties much more thoroughly than their rarer massive counterparts.

Across the Universe, massive stars, which are more than ten times more massive than our Sun and up to a million times more luminous, are playing a critical role in the evolution of our galaxy. They act as a heat source for the interstellar medium and enrich it with heavy elements. Despite their importance, astronomers have a relatively poor understanding of the formation and evolution mechanisms of massive stars. This is not only because they are rare and far away (typically thousands of light-years), but also because they are deeply embedded in dense interstellar gas and dust clouds at their early evolutionary stages. To observe young massive stars requires mid-infrared or longer wavelengths and relatively high angular resolution.

FORCAST was used to peer into the turbulent stellar nursery and uncovered 47 compact objects. In order to understand the nature of these objects, researchers combined the SOFIA observations with data from NASA's Spitzer Space Telescope and Herschel Space Observatory. The resulting spectral energy distributions (SEDs) reveal the brightness over a large wavelength range. The SOFIA-FORCAST 20- and 37-micron observations were essential for this analysis because the fluxes at these wavelengths could include contributions from both the central star and the envelope from which it forms.



A cosmic light show sparked by the formation of massive stars in the W51 stellar nursery. The SOFIA FORCAST mosaic (color) is superposed on a star field (white) from the Sloan Digital Sky Survey. Massive stars like these emit so much energy that they play a critical role in the evolution of our galaxy. *(NASA/SOFIA/Lim and De Buizer et al. and Sloan Digital Sky Survey)*

The SEDs have been compared with predictions from massive star formation models to estimate physical properties. The majority (41 out of the 47) are likely to

(continued on page 14)

About this Spotlight

Paper: Surveying the Giant HII Regions of the Milky Way with SOFIA. I. W51A
Authors: W. Lim, J. M. De Buizer
Reference: 2019, ApJ, 873, 51.

Science Spotlight

David Chuss, *Professor, Villanova University*
Ralph Y. Shuping, *Pipeline Scientist*

Magnetic Fields in the Star Forming Clouds of Orion

One of the fundamental links in the chain of our origin story is the formation of stars and planets out of the interstellar gas and dust that exist in both our own Milky Way Galaxy and in other galaxies. Stars form when these interstellar clouds of gas and dust collapse under their own gravity. However, simple gravitational collapse predicts a galactic star formation rate that is much higher than actually observed. It is thought that this inefficiency is at least partially due to magnetic fields that support the interstellar clouds against collapse; but establishing the role of magnetic fields in the star formation process has been difficult due to limitations in available instrumentation.

Luckily, magnetically aligned interstellar dust grains emit polarized light at far-infrared wavelengths. Hence, far-IR polarization can be used as a proxy for the magnetic field strength and direction in interstellar clouds. The SOFIA HAWC+ instrument is one of only a few far-IR polarimeters that astronomers can use to probe astronomical magnetic fields. The high spatial resolution provided by the 106-inch (2.7-meter) diameter SOFIA telescope and increased sensitivity over previous instruments make HAWC+ the perfect tool to address the role of magnetic fields in the star formation process.

"HAWC+ and SOFIA have a unique and important role in the study of magnetic fields," noted Darren Dowell, the HAWC+ principal investigator at the Jet Propulsion Laboratory. "They combine the angular resolution needed to see detail in the turbulent magnetic fields and the wavelength coverage required to highlight different components of the nearby clouds."

In order to address the role of magnetic fields in star forming clouds, David Chuss from Villanova University and collaborators have obtained HAWC+ observations of the Orion Nebula, which is often used as an archetype or "Rosetta Stone" for understanding high-mass clustered star formation throughout the galaxy. The polarimetry observations have produced some of the most detailed magnetic field line maps to date, with spatial scales of ~0.01 parsecs (53-micron band). Such resolution enables the mapping of the field within the cores of the clouds

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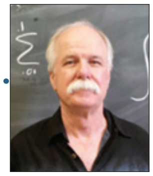
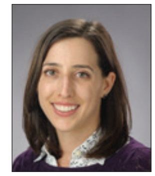
Magnetic fields in the Orion Nebula, shown as streamlines over an infrared image taken by the Very Large Telescope in Chile, are regulating the formation of new stars. SOFIA's HAWC+ instrument is sensitive to the polarized emission from dust grains, which are aligned by magnetic fields. Researchers can use HAWC+ data to infer the direction and strength of these magnetic fields. *(NASA/SOFIA/D. Chuss et al., ESO/M. McCaughrean et al.)*

About this Spotlight

Paper: HAWC+/SOFIA Multiwavelength Polarimetric Observations of OMC-1
Authors: D. T. Chuss, B. Andersson, J. Bally, J. L. Dotson, C. D. Dowell, J. A. Guerra, D. A. Harper, M. Houde, T. J. Jones, A. Lazarian, E. Lopez Rodriguez, J. M. Michail, M. R. Morris, G. Novak, J. Siah, J. Staguhn, J. E. Vaillancourt, C. G. Volpert, M. Werner, E. J. Wollack, D. J. Benford, M. Berthoud, E. G. Cox, R. Crutcher, D. A. Dale, L. M. Fissel, P. F. Goldsmith, R. T. Hamilton, S. Hanany, T. K. Henning, L. W. Looney, S. H. Moseley, F. P. Santos, I. Stephens, K. Tassis, C. Q. Trinh, E. Van Camp, D. Ward-Thompson, and the HAWC+ Science Team
Reference: 2019, ApJ, 872, 187.






Terry Jones, *Emeritus Professor, Minnesota Institute for Astrophysics*
Arielle Moullet, *SOFIA Outreach Scientist*
Kassandra Bell, *Communications Specialist*
Joan Schmelz, *Associate Director for Science and Public Outreach*

Weighing Galactic Wind Provides Clues to Evolution of Galaxies

The Cigar Galaxy (M82) is famous for its extraordinary speed in making new stars, with stars being born 10-times faster than in the Milky Way. Now, data from SOFIA have been used to study this galaxy in further detail, revealing how material that affects the evolution of galaxies may get into intergalactic space.

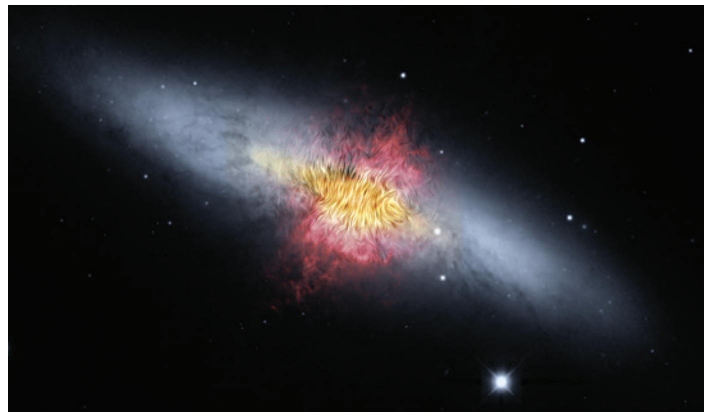
Researchers found, for the first time, that the galactic wind flowing from the center of the Cigar Galaxy (M82) is aligned along a magnetic field and transports a very large mass of gas and dust — the equivalent mass of 50 to 60 million Suns.

"The space between galaxies is not empty," said Enrique Lopez-Rodriguez, a Universities Space Research Association (USRA) scientist working on the SOFIA team. "It contains gas and dust — which are the seed materials for stars and galaxies. Now, we have a better understanding of how this matter escaped from inside galaxies over time."

Besides being a classic example of a starburst galaxy, because it is forming an extraordinary number of new stars compared with most other galaxies, M82 also has strong winds blowing gas and dust into intergalactic space. Astronomers have long theorized that these winds would also drag the galaxy's magnetic field in the same direction, but despite numerous studies, there has been no observational proof of the concept.

Researchers using SOFIA found definitively that the wind from the Cigar Galaxy not only transports a huge amount of gas and dust into the intergalactic medium, but also drags the magnetic field so it is perpendicular to the galactic disc. In fact, the wind drags the magnetic field over more than 2,000 light-years across — close to the width of the wind itself.

"One of the main objectives of this research was to evaluate how efficiently the galactic wind can drag along the magnetic field," said Lopez-Rodriguez. "We did not expect to find the magnetic field to be aligned with the wind over such a large area."



Composite image of the Cigar Galaxy (also called M82), a starburst galaxy about 12 million light-years away in the constellation Ursa Major. The magnetic field detected by SOFIA, shown as streamlines, appears to follow the bipolar outflows (red) generated by the intense nuclear starburst. The image combines visible starlight (gray) and a tracing of hydrogen gas (red) from the Kitt Peak Observatory, with near-infrared and mid-infrared starlight and dust (yellow) from SOFIA and the Spitzer Space Telescope. *(NASA/SOFIA/E. Lopez-Rodiguez; NASA/Spitzer/J. Moustakas et al.)*

These observations indicate that the powerful winds associated with the starburst phenomenon could be one of the mechanisms responsible for seeding material and injecting a magnetic field into the nearby intergalactic medium. If similar processes took place in the early

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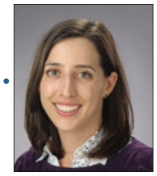
About this Spotlight

Paper: SOFIA Far Infrared Imaging Polarimetry of M82 and NGC 253: Exploring the Super-Galactic Wind
Authors: T. J. Jones, C. D. Dowell, E. Lopez Rodriguez, E. G. Zweibel, M. Berthoud, D. T. Chuss, P. F. Goldsmith, R. T. Hamilton, S. Hanany, D. A. Harper, A. Lazarian, L. W. Looney, J. M. Michail, M. R. Morris, G. Novak, F. P. Santos, K. Sheth, G. J. Stacey, J. Staguhn, I. W. Stephens, K. Tassis, C. Q. Trinh, C. G. Volpert, M. Werner, E. J. Wollack, and the HAWC+ Science Team
Reference: 2019, ApJL, 870, L9.

Science Spotlight

Kassandra Bell, *Communications Specialist*
Joan Schmelz, *Associate Director for Science and Public Outreach*



Lifting the Veil on Star Formation in the Orion Nebula

The stellar wind from a newborn star in the Orion Nebula is preventing more new stars from forming nearby, according to recent research using SOFIA.

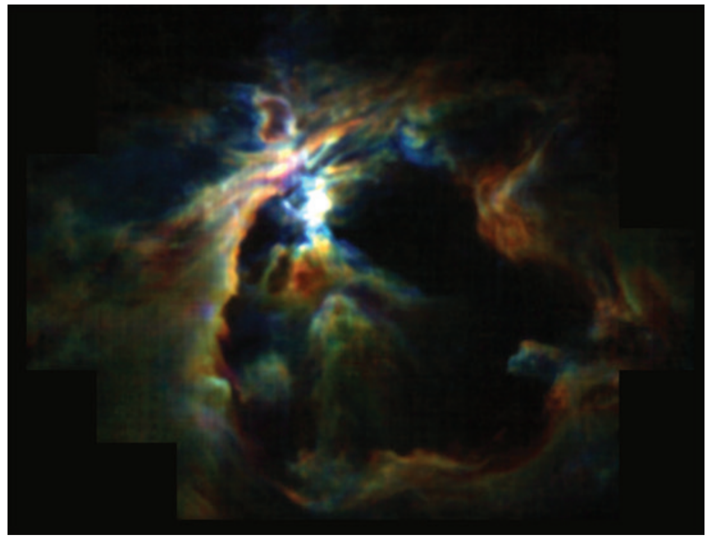
This is surprising because until now, scientists thought that other processes, such as exploding stars called supernovae, were largely responsible for regulating the formation of stars. But SOFIA's observations suggest that infant stars generate stellar winds that can blow away the seed material required to form new stars, a process called "feedback."

The Orion Nebula is among the best observed and most photographed objects in the night sky. It is the closest stellar nursery to Earth, and helps scientists explore how stars form. A veil of gas and dust makes this nebula extremely beautiful, but also shrouds the entire process of star birth from view. Fortunately, infrared light can pierce through this cloudy veil, allowing specialized observatories like SOFIA to reveal many of the star-formation secrets that would otherwise remain hidden.

At the heart of the nebula lies a small grouping of young, massive and luminous stars. Observations from SOFIA's GREAT instrument revealed, for the first time, that the strong stellar wind from the brightest of these baby stars, designated Theta^1 Orionis C (θ^1 Ori C), has swept up a large shell of material from the cloud where this star formed, like a snow plow clearing a street by pushing snow to the road's edges.

"The wind is responsible for blowing an enormous bubble around the central stars," explained Cornelia Pabst, a Ph.D. student at the University of Leiden in the Netherlands and the lead author on the paper. "It disrupts the natal cloud and prevents the birth of new stars."

Researchers used the GREAT instrument on SOFIA to measure the spectral line — which is like a chemical fingerprint — of ionized carbon. Because of SOFIA's airborne location, flying above 99 percent of the water



The powerful wind from the newly formed star, Theta^1 Orionis C, at the heart of the Orion Nebula is creating the bubble (black) as it pushes molecular gas (color) to the edges.

vapor in the Earth's atmosphere that blocks infrared light, researchers were able to study the physical properties of the stellar wind.

"Astronomers use GREAT like a police officer uses a radar gun," explained Alexander Tielens, an astronomer at Leiden Observatory and a senior scientist on the paper. "The radar bounces off your car, and the signal tells the officer if you're speeding."

Similarly, astronomers use the ionized carbon's spectral signature to determine the speed of the gas at all positions

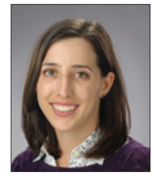
(continued on page 15)

About this Spotlight

Paper: Disruption of the Orion molecular core 1 by wind from the massive star θ^1 Orionis C
Authors: C. Pabst, R. Higgins, J. R. Goicoechea, D. Teyssier, O. Berne, E. Chambers, M. Wolfire, S. T. Suri, R. Guesten, J. Stutzki, U. U. Graf, C. Risacher, A. G. G. M. Tielens
Reference: 2019, Nature, 565, 618.

Science Spotlight






Ralph Y. Shuping, *Pipeline Scientist*
Mikako Matsuura, *Senior Lecturer, Cardiff University*
Kassandra Bell, *Communications Specialist*
Joan Schmelz, *Associate Director for Science and Public Outreach*

SOFIA Finds Dust Survives Obliteration in Supernova 1987A

Cosmic dust, a building block of stars and planets, can form in the wake of a violent stellar explosion called a supernova, according to a new study using SOFIA. These surprising findings provide clues to an astronomical mystery surrounding cosmic dust.

Dust particles form as dying red giant stars throw off material and become part of interstellar clouds of various sizes, densities and temperatures. This cosmic dust is then destroyed by supernova blast waves, which propagate through space at more than 6,000 miles per second (10,000 km/sec)!

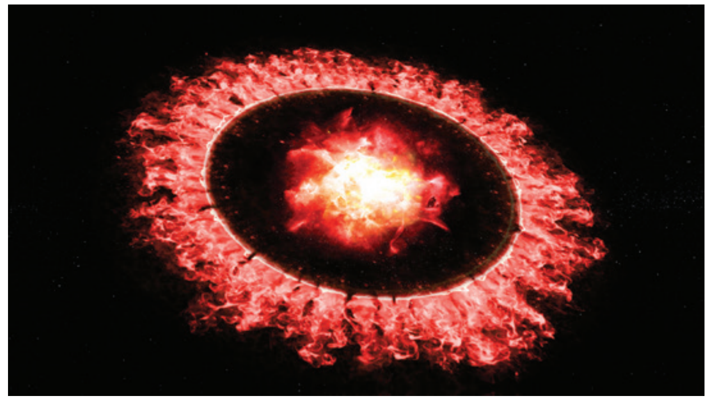
Supernova explosions are among the most powerful events in the universe, with a peak brightness equivalent to the light from billions of individual stars. The explosion also produces a blast wave that destroys almost everything in its path, including dust in the surrounding interstellar medium, the space between the stars.

Current theories predict when a supernova blast sweeps through a region of space, much of the dust would be destroyed, so there should be little dust left. Observations with SOFIA, however, tell a different, mysterious story — revealing more than 10-times the dust expected. This suggests that dust is much more abundant in the wake of a blast wave than theories estimate.

The new study is based on observations of a nearby supernova explosion, called Supernova 1987A. When it was discovered in 1987, it was one of the brightest supernovae seen in 400 years! Due to its close proximity, astronomers have been able to monitor its impact on the surrounding environment continuously for the past 30 years.

SOFIA's observations of the iconic supernova suggest dust may actually be forming in the wake of the powerful blast wave. These results are helping astronomers solve the mystery surrounding the abundance of dust in our galaxy.

"We already knew about the slow-moving dust in the heart of 1987A," said Mikako Matsuura, a senior lecturer at Cardiff University, in the United Kingdom, and the lead author on the paper. "It formed from the heavy elements created in the core of the dead star. But the SOFIA observations tell us something new about a completely unexpected dust population."



Artist's concept illustrating Supernova 1987A as the powerful blast wave passes through its outer ring and destroys most of its dust, before the dust re-forms or grows rapidly. SOFIA observations reveal that this dust — which makes up the building blocks of stars and planets — can re-form or grow immediately after the catastrophic damage caused by the supernova's blast wave. *(NASA/SOFIA/Symbolic Pictures/ The Casadonte Group)*

The observations were published in a recent issue of Monthly Notices of the Royal Astronomical Society.

Supernova 1987A has a distinctive set of rings that are part of a cavity created in an earlier, pre-explosion phase of the star's evolution. The fast-expanding blast wave has

(continued on page 11)

About this Spotlight

Paper: SOFIA Mid-infrared Observations of Supernova 1987A in 2016 — Forward Shocks and Possible Dust Re-formation in the Post-shocked Region
Authors: M. Matsuura, J. M. De Buizer, R. G. Arendt, E. Dwek, M. J. Barlow, A. Bevan, P. Cigan, H. L. Gomez, J. Rho, R. Wesson, P. Bouchet, J. Danziger, M. Meixner
Reference: 2018, MNRAS, 2018.

Science Spotlight



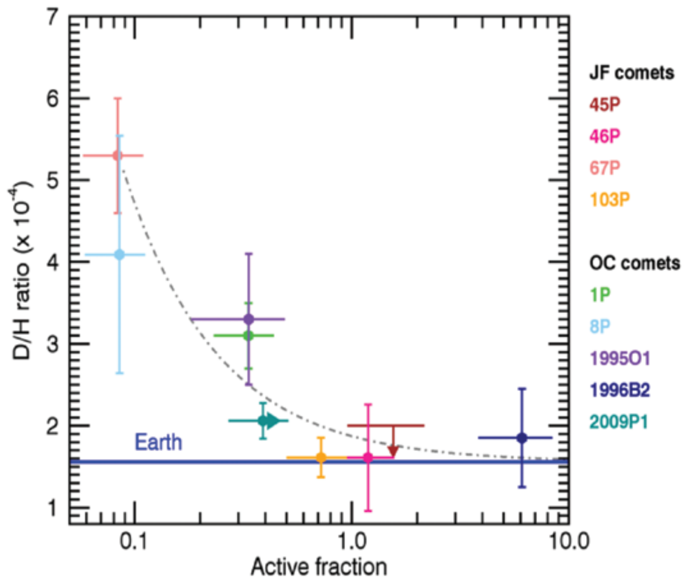
Darek Lis, *Scientist, Jet Propulsion Laboratory*
Dominique Bockelée-Morvan, *Research Director, LESIA, CNRS, Observatoire de Paris, PSL*
Rolf Güsten, *Senior Scientist, MPIfR*

SOFIA Observations Fuel Debate about the Origin of the Earth's Oceans

One of the key questions for modern astrophysics and planetary science concerns the development of the conditions of habitability in planetary systems, such as the early protosolar nebula. Water is an essential ingredient for carbon-based life as we know it. However, the source of terrestrial water is still unknown. In the standard model of the protosolar nebula, the temperature in the terrestrial planet-forming zone was too high for water ice to survive. Consequently, the Earth accreted dry and the present-day water had to be delivered in a later phase, together with organics, by external sources such as comets or asteroids.

Comets are the most primitive volatile-rich bodies in the solar system. The deuterium to hydrogen isotopic ratio in cometary water (the D/H ratio) has been shown to vary between one- and three-times the Earth's oceans value, in both Oort cloud comets and Jupiter-family comets originating from the Kuiper belt. This has been taken as evidence that comets contributed a relatively small fraction of the terrestrial water. New sensitive spectroscopic observations of water in the Jupiter-family comet 46P/Wirtanen, carried out using the GREAT spectrometer aboard SOFIA, give the same D/H ratio as in the Earth's oceans. Although the statistics are limited, interesting trends are already becoming apparent in the existing data. A striking anti-correlation is seen between the D/H ratio in water and the active fraction, defined as the ratio of the active surface area to the total nucleus surface (see figure). Hyperactive comets with high active fractions, such as 46P/Wirtanen, typically have D/H ratios in water consistent with the terrestrial value. These comets require an additional source of water vapor in their coma, explained by the presence of subliming icy grains expelled from the nucleus.

The observed anti-correlation may suggest that hyperactive comets belong to a population of ice-rich objects that formed just outside the snow line, or in the



The D/H ratio in cometary water as a function of the active fraction. The blue horizontal line corresponds to the Earth's ocean value. The dashed-dotted line shows the expected ratio assuming two sources of water: D-rich (3.5×terrestrial) from the nucleus and terrestrial.

outermost regions of the solar nebula, from water thermally reprocessed in the inner disk that was transported outward during the early disk evolution. However, based on a large comet sample, hyperactivity is only observed for small comet nuclei. This seems to argue against the first interpretation, as planetesimals near the snow line are expected to undergo rapid growth. Alternatively, isotopic properties of water outgassed from the nucleus and icy grains may be different due to fractionation

About this Spotlight

Paper: Terrestrial deuterium-to-hydrogen ratio in water in hyperactive comets
Authors: D. C. Lis, D. Bockelée-Morvan, R. Güsten, N. Biver, J. Stutzki, Y. Delorme, C. Durán, H. Wiesemeyer, Y. Okada
Reference: A&A Letters, in press.

effects at sublimation. In this case, all comets may share the same Earth-like D/H ratio in water, with profound implications for the early solar system and the origin of the Earth's oceans.

Enlarging the number of accurate D/H measurements in both Jupiter-family and Oort cloud comets is of paramount importance for understanding the origin of the Earth's water. Such measurements, carried out at submillimeter, infrared, or UV wavelengths, are challenging from the ground, leading to large observational uncertainties. SOFIA, with its newly upgraded GREAT instrument, can play a key role in this endeavor, critical for understanding planetary habitability. ■

Weighing Galactic Wind Provides Clues to Evolution of Galaxies

(continued from page 7)

Universe, they would have affected the fundamental evolution of the first galaxies.

SOFIA's newest instrument, HAWC+, uses far-infrared light to observe celestial dust grains, which align along magnetic field lines. From these results, astronomers can infer the shape and direction of the otherwise invisible magnetic field. Far-infrared light provides key information about magnetic fields because the signal is clean and not contaminated by emission from other physical mechanisms, such as scattered visible light.

"Studying intergalactic magnetic fields — and learning how they evolve — is key to understanding how galaxies evolved over the history of the Universe," said Terry Jones, professor emeritus at the University of Minnesota, in Minneapolis, and lead researcher for this study. "With SOFIA's HAWC+ instrument, we now have a new perspective on these magnetic fields."

The HAWC+ instrument was developed and delivered to NASA by a multi-institution team led by the Jet Propulsion Laboratory (JPL). JPL scientist and HAWC+ Principal Investigator Darren Dowell, along with JPL scientist Paul Goldsmith, were part of the research team using HAWC+ to study the Cigar Galaxy. ■

SOFIA Finds Dust Survives Obliteration in Supernova 1987A

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passed through these ring structures. Astronomers thought that any dust particles in these rings would have been destroyed, but recent observations from SOFIA show emission consistent with a growing population of dust in the rings. The results indicate that dust particles can re-form or grow rapidly, even after the catastrophic damage caused during the passage of the blast wave, suggesting that although this might be the end of a chapter in the life cycle of dust, it does not appear to be the end of the story.

The dust detected by SOFIA could result from either significant growth of the existing dust particles or the formation of a new dust population. These new observations compel astronomers to consider the possibility that the post-blast environment might be ready to form or re-form dust immediately after the blast wave passes — a new clue that may be pivotal in resolving the discrepancy between dust destruction models and observations.

From ground-based telescopes on Earth, observing cosmic dust particles in the infrared is difficult — or impossible — due to strong absorption, primarily from water and carbon dioxide in the Earth's atmosphere. By flying above most of the obscuring molecules, SOFIA provides access to portions of the infrared spectrum not available from the ground. In particular, SOFIA's FORCAST is a powerful instrument for understanding warm dust in particular.

"FORCAST is the only instrument that can observe at these critical wavelengths and detect this newly forming population of warm dust," said James De Buizer, the USRA manager for science operations at the SOFIA Science Center and co-author on the study. "We plan to continue monitoring with FORCAST to gain more insight into dust creation and evolution in supernova remnants." ■

German Perspective

Bernhard Schulz, *Science Mission Operations Deputy Director*

When this issue of the newsletter comes out, SOFIA will already be in its seventh cycle. Last October I participated in the deliberations of the Time Allocation Committee (TAC) as an observer, providing me with a good insight into the process. Of the 33 German proposals for Open Time, nine proposals with 45 hours were awarded "Must Do" or "Should Do" time. These proposals have a high probability of completion and any unfinished parts of "Must Do" proposals will be carried over into the next cycle. Analysis of prior cycles shows that for each scheduled hour of the aforementioned grades, a certain percentage of additional "filler" observations is needed, of which many will be completed as well. A total of 14 German proposals received another 62 hours in this "Do if time" category. Two Legacy Programs were successful, of which the larger one has significant German participation. I would like to extend a big "Thank You!" to all our German panel members with the chair, Hans Zinnecker, who spent a significant amount of time, effort, and expertise on providing me with final grades, so that together with the U.S. results, we could construct another balanced, high-quality observing program.

All of this proceeded in parallel to the preparations for both the SOMER and the FMR that replace the originally planned NASA Senior Review, allowing a German participation in both reviews. Keeping this five-year review cycle, instead of the three-years required by the Senior Review, would be important for our efforts thereby bringing the German instrumentation funding back onto a more solid footing. At the time of writing, we had just submitted the FMR proposal, which makes a great case for the unique and compelling science only SOFIA can tackle in the short and mid-term future. I am looking forward to receiving the recommendations of both reviews, and the subsequent synthesis we will have to create, as this provides us with a great opportunity to improve all aspects of our observatory, and renew and strengthen our international partnership for years to come.

The aircraft is in good shape and it seems that last year's tweaks to the way maintenance is managed are paying off. The German SOFIA Institute team just replaced the mechanism of the secondary mirror with an improved spare that will reduce vibrations and time-constants, thus increasing observational efficiency. I recently was very impressed during a tour of the spare parts vault at NASA's Armstrong Flight Research Center in Palmdale, California. Thousands of parts, salvaged from other 747SP aircraft, have been collected, inspected, overhauled and stored, to minimize procurement and down-times.

It was especially pleasing to see the recent increase in the rate of scientific publications. The *Nature* paper by Pabst et al. (2019) was certainly a highlight, providing more insight into the importance of stellar winds for the disruption of molecular clouds in Orion and thus the regulation of star formation. Another noteworthy publication by Appleton et al. (2018) features extragalactic observations of shock and turbulence induced [CII] emission in NGC 4258 with FIFI-LS. I should also mention the special Issue of the *Journal of Astronomical Instrumentation*, featuring 14 articles of which seven are led by German authors.

After Jürgen Stutzki succeeded Rolf Güsten last year as GREAT Principal Investigator, a new chair for the German SOFIA Science Working Group (GSSWG) was needed. Sebastian Wolf, professor at the University of Kiel, agreed to take on this important position and he will also serve as the German co-chair at the next SOFIA International Summit.

This year the annual conference of the *Astronomische Gesellschaft* will convene September 16–20 in Stuttgart, and we are planning to show SOFIA there during the same week, pending final agreement by NASA. Several special SOFIA-related sessions are already being organized, so this should be a very interesting meeting to look forward to. Finally, I'd like to draw your attention to this year's Call for Proposals, that should be released again at the beginning of June, with a proposal deadline of September 6, 2019. ■

Science Operations and Outreach

B-G Andersson, *Associate Director for Science Operations*

The final series of Cycle 6 and first several series of Cycle 7 are being executed and planned as I write this, and it's good to be back flying! The government shutdown last winter necessitated a fair amount of re-planning for Cycle 6 SOFIA operations, and delayed some of the future cycle planning. With a lot of hard work and swift responses, we managed to recover a couple of short HAWC+ and FIFI-LS series flights after the shutdown ended and before the required aircraft maintenance period in March/April. We then picked up the original plan with the Observing Cycle 6-S (OC6S) flight series with EXES.

We have also finalized the plans for Cycle 7, including the southern deployment. With flexibility and can-do from the whole SOFIA team, a way was found to again support three instruments in the deployment to New Zealand: the GREAT, FORCAST, and HAWC+. A large part of the southern observing time will be taken up by the first two SOFIA Legacy programs. The first one is a GREAT-based study of the interaction of massive stars with their environments, from single OB stars to mini starbursts. This joint U.S.- and German-queue program is led by Alexander Tielens of Leiden University, The Netherlands, and Nicola Schneider of University of Cologne, Germany. The second Legacy program consists of FORCAST imaging at 25 and 37 microns of warm dust emission from infrared-bright portions of the Galactic center including the inner ~50 parsecs, Sagittarius B2, and Sagittarius C. This program is led by Matthew Hankins of Caltech, Pasadena, California.

The over-all schedule for SOFIA Cycle 7 has also been optimized with a baseline plan shown in Table 1.

Table 1. Cycle 7 Flight Series

Flight Series	Instrument	# of flights	Month
OC7A	FIFI-LS	9+3	May 2019
OC7B	GREAT	2+1	May 2019
OC7C	GREAT (NZ)	12+4	June 2019
OC7D	FORCAST (NZ)	6+2	July 2019
OC7E	HAWC+ (NZ)	6+2	July 2019
OC7F	HAWC+	14+4	September 2019
OC7G	FORCAST	8+2	October 2019
OC7H	FIFI-LS	8+3	November 2019
OC7I	GREAT	10+4	November 2019
OC7J	HAWC+	9+3	January 2020
OC7K	EXES	6+2	February 2020
OC7L	FIFI-LS	6+2	February 2020
OC7M	GREAT	9+3	March 2020
OC7N	FORCAST	3+1	March 2020
OC7O	EXES	3+1	March 2020

The two numbers in the column for the "Number of flights" reflect the nominal flights and the contingency flights planned. The division into these two categories is based on a detailed study of SOFIA departure statistics, and is intended to ensure that the highest ranked programs can be completed in the cycle. We will schedule, and execute, the contingency flights with (lower priority) Cycle 7 programs, but those flights will be used to "re-try" any nominal flights that did not go off as planned.

The Cycle 8 Call for Proposals is also being finalized at the time of writing. We plan to offer all the instruments and modes from Cycle 7, including Legacy programs. In addition, a SOFIA archival-data program will be offered. We're also working on the final definition of a pilot program for a Joint Observations option, whereby a successful SOFIA program will be able to access a limited number of ground-based observatories for programs that require such complementary data sets. Please look for details in the released Call for Proposals. ■

The Universe's First Type of Molecule is Found at Last

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of the early universe (He + H^+ -> HeH^+ + hν). Future studies of HeH^+ ($J=1$-0 and $J=2$-1 at 149 and 75 µm, respectively) can help us further study overlap ionization regions in planetary nebulae.

SOFIA made this discovery possible by accessing the electromagnetic spectrum in the region where the HeH^+ can be detected and having the sensitivity and technology to measure the rotational ground-state $J=1$-0 transition at 149.137 microns with high-enough spectral resolution to separate it from the nearby Λ-doublet of CH at 149.09 and 149.39 microns. CH is among many molecules abundant in photodissociation regions, and had been previously detected in NGC 7027 with the Infrared Space Observatory's Long Wavelength Spectrometer (LWS). However, LWS's spectral resolution was too low to distinguish the adjacent HeH^+ transition from the CH, and the authors from that study provided an HeH^+ upper limit (see Liu, X.W. et al. MNRAS, 290, L71-L75 [1997]). The latest advances in terahertz technology enabled this first unambiguous HeH^+ detection in interstellar space by GREAT on SOFIA. ■

The Most Luminous Protostar

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is added every thousand years.

The right panel of the figure (page 4) shows the same region, now viewed at much shorter, near infrared wavelengths from one to two microns. This image reveals a diffuse glow from even higher temperature dust, but the overlaid 37-micron emission extends much further, showing the dramatic influence of the massive protostar out to tens of light years. Within this region, the near infrared image also shows the presence of a cluster of stars around the protostar, most of which are not strong emitters at 37 microns. The precise role this cluster is playing in influencing the birth of this most luminous protostar remains to be determined, but this should be possible to answer soon in a general sense from analysis of the growing sample, now about 40 strong, of sources characterized by the SOMA survey. ■

SOFIA Captures Cosmic Light Show of Star Formation

(continued from page 5)

be massive young stellar objects, many of which are identified as such for the first time in this work. Close to half of the massive young stellar objects do not have detectable radio continuum emission at centimeter wavelengths. This implies a very young state of formation since the stars have not yet developed a surrounding zone of ionized gas.

One of the compact objects was surprisingly bright across all wavelengths. Modeling of these data indicates that it may be exceptionally large, with the equivalent mass of 100 Suns. If future observations confirm that it is indeed a single, colossal star, rather than multiple stellar siblings clustered together, it would be one of the most massive forming stars in our galaxy.

Another part of the study was the quantitative analysis of the star formation history in W51A, which confirmed and improved upon earlier results. The luminosity-to-mass ratio, which traces the evolutionary state, was derived for several regions to estimate their relative ages. The oldest, most evolved area is in the upper left of the image (page 5). The complex in the lower right is significantly younger, but the youngest region is located near the center of the image. There are indications that the collision of interstellar clouds at this location caused this most recent episode of star formation. ■

Magnetic Fields in the Star Forming Clouds of Orion

(continued from page 6)

where the later stages of the star formation process occurs. These observations confirm previous results showing that magnetic fields *do* in fact help regulate the star formation process in dense interstellar clouds.

The high-resolution polarimetry maps have produced two additional interesting results. The first pertains to the process by which the dust grains become aligned. The grain-alignment mechanism is the subject of great interest both because it provides the basis for the measurements of magnetic fields and because it provides key, testable insights into the physics of the dust and its environs. The current leading theory posits that anisotropic radiation fields are an important ingredient for the alignment of the grains with the magnetic field. In other clouds, it has been observed that grain alignment efficiency degrades in the cores of clouds, presumably where the grains are shielded from the interstellar radiation field. However, in Orion Molecular Cloud 1 (OMC-1), these results show no evidence that the efficiency of this alignment process falls off in dense regions. This is likely due to the nature of the strong radiation field present within the OMC-1 clouds, presumably due to the young stars themselves.

A second result is that the magnetic field traces the "explosive outflow" emanating from the heart of the OMC-1. This explosion of material was likely caused 500–1,000 years ago by an interaction of several stars after the orbital decay of a protostellar star system.

"Explosive outflows indicate violent interactions which may terminate accretion, set stellar masses, and help establish the initial mass function," explains Professor John Bally of the University of Colorado at Boulder and a co-investigator on the HAWC+ OMC-1 observations. "Explosive outflows, in conjunction with runaway stars, demonstrate that dynamical interactions in such groups are an important ingredient in star formation."

Near the center of the explosion, the magnetic fields are overwhelmed by the energetics of the explosion; however, farther out, the kinetic energy is weaker and it appears that the magnetic fields are guiding the ejecta. The magnetic field measurements provide valuable constraints on the energetics of this unique outflow.

These results for Orion are powerful examples of the utility of SOFIA-HAWC+ in understanding magnetic fields in star forming clouds. Future results will continue to advance our understanding of the role of magnetic fields in the interstellar medium in general, and in the star formation process in particular.

"It has been thrilling to have a front row seat to the teamwork needed to accomplish these observations," added Dowell. "I look forward to discovering whether Orion is the exception or the rule in other galactic clouds." ■

Lifting the Veil on Star Formation in the Orion Nebula

(continued from page 8)

across the nebula and study the interactions between massive stars and the clouds where they were born. The signal is so strong that it reveals critical details and nuances of the stellar nurseries that are otherwise hidden. But this signal can only be detected with specialized instruments — like GREAT — that can study far-infrared light.

At the center of the Orion Nebula, the stellar wind from Theta^1 Orionis C forms a bubble and disrupts star birth in its neighborhood. At the same time, it pushes molecular gas to the edges of the bubble, creating new regions of dense material where future stars might form.

These feedback effects regulate the physical conditions of the nebula, influence the star formation activity, and ultimately drive the evolution of the interstellar medium, the space between stars filled with gas and dust. Understanding how star formation interacts with the interstellar medium is key to understanding the origins of the stars we see today, and those that may form in the future. ■

SOFIA Images Featured on Astronomy Picture of the Day

February 27, 2019: Can magnetism affect how stars form? Recent analysis of Orion data from the HAWC+ instrument on the SOFIA observatory indicate that, at times, it can. HAWC+ is able to measure the polarization of far-infrared light which can reveal the alignment of dust grains by expansive ambient magnetic fields. In the featured image, these magnetic fields are shown as curvy lines superposed on an infrared image of the Orion Nebula taken by the Very Large Telescope in Chile. Orion's Kleinmann-Low Nebula is visible slightly to the upper right of the image center, while bright stars of the Trapezium cluster are visible just to the lower left of center. The Orion Nebula at about 1,300 light years distant is the nearest major star formation region to the Sun. *(NASA, SOFIA, D. Chuss et al. & ESO, M. McCaughrean et al.)*

March 11, 2019: Are galaxies giant magnets? Yes, but the magnetic fields in galaxies are typically much weaker than on Earth's surface, as well as more complex and harder to measure. Recently, though, the HAWC+ instrument onboard SOFIA has been successful in detailing distant magnetic fields by observing the polarized infrared light emitted by elongated dust grains rotating in alignment with the local magnetic field. HAWC+ observations of M82, the Cigar galaxy, show that the central magnetic field is perpendicular to the disk and parallel to the strong supergalactic wind. This observation bolsters the hypothesis that M82's central magnetic field helps its wind transport the mass of millions of stars out from the central star-burst region. The featured image shows magnetic field lines superposed on top of an optical light (gray) and hydrogen gas (red) image from Kitt Peak National Observatory, further combined with infrared images (yellow) from SOFIA and the Spitzer Space Telescope. The Cigar Galaxy is about 12 million light years distant and visible with binoculars toward the constellation of the Great Bear. *(NASA, SOFIA, E. Lopez-Rodriguez; NASA, Spitzer, J. Moustakas et al.)*

SOFIA is a Boeing 747SP jetliner modified to carry a 106-inch diameter telescope. It is a joint project of NASA and the German Aerospace Center, DLR. NASA's Ames Research Center in California's Silicon Valley manages the SOFIA program, science and mission operations in cooperation with the Universities Space Research Association headquartered in Columbia, Maryland, and the German SOFIA Institute (DSI) at the University of Stuttgart. The aircraft is maintained and operated from NASA's Armstrong Flight Research Center, Building 703, in Palmdale, California.

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